Development of Decision-Making Software for Patients With Kidney Stones

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Abstract—The paper discusses the development of decision-making software for patients with kidney stones. Computerized decision–making about treatment choices for patients with renal stones is step-by-step described in this paper. Medicine is one of the sectors where computerized decision-making is being used more often. One of the key elements of expert systems – building a knowledge base that is based on recommendation fund, known as „Guidelines“, is discussed. The paper discusses the most frequently used therapies. Examples of decision trees and production rules are shown.

Keywords—Decision making, kidney stones, production rules.

I. INTRODUCTION

Nowadays more and more attention is paid to computerized decision-making processes. Different computer programs are developed which allow us to make a decision in several sectors. Such software is designed to facilitate daily work of specialists. Medicine if one of the sectors where computerized decision–making is being used more often. One of the latest software is the computerized decision-making of treatment choices for patients with kidney stones. The existing knowledge of this sector is summarized in the collection of recommendations, known as „Guidelines“, which is useful for the computerized decision-making development process.

Kidney stones can be found in an average of 10 – 20 of 10,000 people. The number of patients with kidney stones in the developed countries is gradually increasing. One of the factors why this is happening is the increased protein usage in the diet, inactive lifestyle or lack of fluid intake [3], [12], [14]. In simple cases kidney stones can be dissolved using medications, and stones will pass out by themselves [15]. In more complex situations, it is necessary to perform multiple surgical procedures and patients may need to stay in hospital for several days [2, 13].

II. PROPOSED METHOD

To create a computerized decision–making of treatment choices for patients with kidney stones, guidelines of urolithiasis were used [2]. There are several steps to develop a fully working software, starting with knowledge base creation and finishing with computer program testing.

Step 1) At the beginning all possible diagnoses must be selected for patients with kidney stones. Kidney stones can be located in urinary tract, kidneys and bladder. This paper provides decision–making in cases when the stones are only in kidneys. Regardless where kidney stones are, diagnosis is divided in two parts:
- Uncomplicated kidney stones (without infection);
- Complicated kidney stones (infectious).

In this case there in fact are only two, if kidney stone features (composition, size, and location in the kidney) are not mentioned. Problems begin when it is necessary to choose the optimal therapy, where all stone features and indications, as well as contraindications must be examined and used [2], [3].

Step 2) All possible therapies must be selected. Therapies can be divided in two groups [4]:
- Conservative therapy;
- Surgical therapy.

Conservative therapy holds all types of drug treatment, from simple analgesics to oral chemotherapy. Surgical therapies are [2], [5], [6], [10], [11]:
- Stenting;
- Extracorporeal shock wave lithotripsy (ESWL);
- Ureterscopy (URS) or Retrograde Intrarenal Surgery (RIRS);
- Percutaneous nephrolithotomy (PNL);
- Laparoscopy;
- Open Surgery.

After that a priority table of treatment choices must be created using composition and size of renal stones. Unfortunately practice shows that renal stone features give no information about the patient, but this kind of information is crucial and must be used for the decision-making [9], [16]. Each therapy gets its own indications that allow to use the selected therapy but there can be one or more contraindications prohibiting the selected therapy. Table 1 gives an example of one of the therapies [2], [3], [8], [9].

Step 3) Since the knowledge base structure is based on decision trees, the information is stored using production rules. Production rules consist of a condition (IF) and action (THEN). Formally it is written: IF (condition) and THEN (action).

The decision tree consists of decision nodes (Indications), chance nodes (contraindications) and end nodes (therapies) [7]. Decision trees must be created for each indication. To make this process easier all indications and contraindications are indexed and later these indexes are used during the programming process. Ureterscopy indication indexes are [1]:
- Ind6_1 Unsuccessful ESWL therapy;
- Ind6_2 Nephrocalcinosis;
- Ind6_3 Severe obesity;
- Ind6_4 Stones in kidneys and urinary tract at the same time.

The contraindications are:
- K_1 Uncontrolled urinary tract infections (UTIs);
- K_4 Intrarenal anatomical abnormalities;
- K_5 Urinary stasis;
- K_14 Bleeding diathesis.

The ureterscopy decision tree can be seen in Fig. 1.
In order not to draw exactly the same four trees, where the only difference is decision nodes (Indications), a decision tree was drawn where all four indications are at the decision node and indexed it with Ind_6.

PR 1 (Branch A)  IF there is Ind_6 AND (no K_1) AND (no K_5) AND (no K_14) AND (no K_4) THEN „Ureteroscopy”;

PR 2 (Branch B)  IF there is Ind_6 AND (yes K_14) AND (no K_4) AND (yes K_1) AND (no K_5) THEN „Give Platelets” AND „Ureteroscopy”;

PR 3 (Branch D+E)  IF there is Ind_6 AND (yes K_1) AND (yes K_5) AND (no K_14) AND (no K_4) THEN go to “Infection tree”;  

PR 4 (Branch C+D+E)  IF there is Ind_6 AND (yes K_4) AND (yes K_1) AND (yes K_5) AND (no K_14) THEN go to „Infection tree” AND „Use Laparoscopy or Open Surgery”;  

PR 5 (Branch B+C+D+E)  IF there is Ind_6 AND (yes K_4) AND (yes K_1) AND (yes K_5) AND (yes K_14) THEN go to „Infection tree” AND „Give platelets” AND „Use Laparoscopy or Open Surgery”;  

By the same technique decision trees are made for all indications, followed by all possible production rule combinations between the tree branches.

Extracorporeal shock wave lithotripsy has much more indications and contraindications as it can be seen in Table 1. ESWL indications are [1]:

<p>| Indication and Contraindication Table for Ureteroscopy and Extracorporeal Shock Wave Lithotripsy |
|--------------------------------------|---------------------------------------------|---------------------------------------------|</p>
<table>
<thead>
<tr>
<th><strong>Therapy</strong></th>
<th><strong>Indications</strong></th>
<th><strong>Contraindications</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ureteroscopy (URS)</td>
<td>• Unsuccessful ESWL therapy</td>
<td>• Uncontrolled urinary tract infections (UTIs)</td>
</tr>
<tr>
<td></td>
<td>• Nephrocalcinosis</td>
<td>• Urinary stasis</td>
</tr>
<tr>
<td></td>
<td>• Severe obesity</td>
<td>• Intrarenal anatomical abnormalities</td>
</tr>
<tr>
<td></td>
<td>• Stones can be found in both kidneys and urinary tract</td>
<td>• Bleeding diathesis</td>
</tr>
<tr>
<td>Extracorporeal shock wave lithotripsy (ESWL)</td>
<td>• Calcium stones smaller than 20 mm</td>
<td>• Pregnancy</td>
</tr>
<tr>
<td></td>
<td>• Cystine stones smaller than 20 mm</td>
<td>• Severe skeletal malformations</td>
</tr>
<tr>
<td></td>
<td>• Diabetes</td>
<td>• Arterial aneurysm</td>
</tr>
<tr>
<td></td>
<td>• Hypertension</td>
<td>• Uncontrolled urinary tract infections (UTIs)</td>
</tr>
<tr>
<td></td>
<td>• Respiratory diseases</td>
<td>• Severe obesity</td>
</tr>
<tr>
<td></td>
<td>• Patient with a single kidney</td>
<td>• Non-functioning kidney</td>
</tr>
<tr>
<td></td>
<td>• Not allowed to use anesthesia and open surgery</td>
<td>• Urinary stasis</td>
</tr>
<tr>
<td></td>
<td>• Patient who recently had a surgery</td>
<td>• Prolapsed kidney</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Uncontrolled urinary tract infections (UTIs)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Severe obesity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Nephrocalcinosis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Intrarenal anatomical abnormalities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Bleeding diathesis</td>
</tr>
<tr>
<td>Laparoscopy and open surgery</td>
<td>• Infectious stone burden</td>
<td>• Blood coagulation problems</td>
</tr>
<tr>
<td></td>
<td>• Unsuccessful ESWL, PNL and URS therapies</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Intrarenal anatomical abnormalities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Severe obesity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Non-functioning kidney</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Severe skeletal malformations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Arterial aneurysm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Prolapsed kidney</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Step 4) The next step is to write the production rules. At the beginning the rules are written for each branch separately and afterwards all possible branch combinations must be described. Note: Not all production rules are shown:
ESWL contraindication indexes are:

\[
\begin{align*}
K_1 & \text{ Uncontrolled urinary tract infections (UTIs);} \\
K_4 & \text{ Intrarenal anatomical abnormalities;} \\
K_5 & \text{ Urinary stasis;} \\
K_6 & \text{ Prolapsed kidney;} \\
K_7 & \text{ Non-functioning kidney;} \\
K_8 & \text{ Severe skeletal malformations;} \\
K_{10} & \text{ Arterial aneurysm;} \\
K_{11} & \text{ Severe obesity;} \\
K_{12} & \text{ Unsuccessful ESWL therapy.}
\end{align*}
\]

ESWL decision tree can be seen in Fig. 2.

Production rules are written for each branch separately and for all possible combinations too. Note: Not all production rules are shown.

**PR 1 (Branch A)**

IF there is Ind_5 AND (no K_8) AND (no K_{10}) AND (no K_1) AND (no K_{11}) AND (no K_7) AND (no K_6) AND (no K_4) AND (no K_5) AND (no K_{12})

THEN „ESWL” therapy;

**PR 2 (Branch D)**

IF there is Ind_5 AND (yes K_1) AND (no K_5) AND (no K_{12}) OR (no K_{11}) AND (no K_8) OR (no K_{10}) OR (no K_7) OR (no K_6) OR (no K_4)

THEN go to „Infection tree”.

**PR 3 (Branch E)**

IF there is Ind_5 AND (yes K_5) AND (no K_1) AND (no K_{11}) OR (no K_{12}) AND (no K_8) OR (no K_{10}) OR (no K_7) OR (no K_6) OR (no K_4)

THEN „Stenting”;

**PR 4 (Branch B+D)**

IF there is Ind_5 AND (yes K_{10}) OR (yes K_8) OR (yes K_7) OR (yes K_6) OR (yes K_4) AND (yes K_1) AND (no K_5) AND (no K_{12}) OR (no K_{11})

THEN go to “Infection tree” AND „Use Laparoscopy or Open Surgery”;

**PR 5 (Branch D+E)**

IF there is Ind_5 AND (yes K_1) AND (yes K_5) AND (no K_8) OR (no K_{10}) OR (no K_7) OR (no K_6) OR (no K_4) AND (no K_{12}) OR (no K_{11})

THEN go to “Infection tree” AND „ESWL” therapy;

**PR 6 (Branch B+C+D)**

IF there is Ind_5 AND (yes K_8) OR (yes K_{10}) OR (yes K_7) OR (yes K_6) OR (yes K_4) AND (yes K_{12}) OR (yes K_{11}) AND (yes K_1) AND (no K_5)

THEN go to “Infection tree” AND „Use Laparoscopy or Open Surgery”;

**PR 7 (Branch B+C+E)**

IF there is Ind_5 AND (yes K_8) OR (yes K_{10}) OR (yes K_7) OR (yes K_6) OR (yes K_4) AND (yes K_{12}) OR (yes K_{11}) AND (yes K_5) AND (no K_1)

THEN “Stenting” AND „Use Laparoscopy or Open Surgery”;

**PR 8 (Branch B+C+D+E)**

IF there is Ind_5 AND (yes K_8) OR (yes K_{10}) OR (yes K_7) OR (yes K_6) OR (yes K_4) AND (yes K_{12}) OR (yes K_{11}) AND (yes K_5) AND (yes K_1)

THEN go to “Infection tree” AND „Use Laparoscopy or Open Surgery”.

There is a possibility that the decision must be made by moving from one tree to another. The decision process can be cyclic. Such an example is the production rule 2 (Branch D) from Extracorporeal shock wave lithotripsy tree. It says that the therapy is “Infection tree”. If the patient has got the uncontrolled urinary tract infection (UTIs), it will always lead to the infection tree. This tree differs from the others, because
there is only one contraindication which determines the sequence of therapy. The contraindication is:

K_{13} Situation is life-threatening. Act immediately.

If the decision tree gives more than one therapy, all of them must be performed in the given order.

The infection decision tree can be seen in Fig. 3.

The production rules are:

PR 1 IF there is (UTI's) AND (no K_{13})
THEN “Stenting”
AND “Treat infection with antibiotics”
AND “Treat kidney stones by using one of the surgical therapies”;

PR 2 IF there is (UTI's) AND (yes K_{13})
THEN “Stenting”
AND “use Laparoscopy or Open surgery”
AND “Treat infection with antibiotics”.

There is a possibility that the decision can be made by cyclic operations within one tree. Such an example is the Laparoscopy and Open surgery decision tree. Indications and contraindications can be seen in Table I. Indication indexes are:

Ind14_1 Infectious stone burden;
Ind14_2 Unsuccessful ESWL, PNL and URS therapies;
Ind14_3 Intrarenal anatomical abnormalities;
Ind14_4 Severe obesity;
Ind14_5 Non-functioning kidney;
Ind14_6 Severe skeletal malformations;
Ind14_7 Arterial aneurysm;
Ind14_8 Prolapsed kidney.

Contraindication index is:

K_{14} Blood coagulation problems.

Laparoscopy and open surgery have exactly the same decision trees because all indications and contraindications are the same. Laparoscopy is less invasive so it is always going to have higher priority than the open surgery. In order not to draw exactly the same eight trees, where the only difference is decision nodes (Indications), a decision tree has been drawn where all eight indications are at the decision node and are indexed with Ind_14. The decision tree can be seen in Fig. 4.

The production rules are:

PR 1 IF there is Ind_14 AND (no K_{14})
THEN “Use Laparoscopy or Open surgery”;

PR 2 IF there is Ind_14 AND (yes K_{14})
THEN “Give platelets” AND “Use Laparoscopy or Open surgery”.

III. SOFTWARE AND USER INTERFACE

The software is based on Microsoft Visual Studio, C# programming language. To save patient data and results, FireBird database is used. To manage and modify database IBExpert was used.

It is possible to save all patient data and test results with all selected indications and contraindications that were used during the test process. The database consists of two tables. The patient table and the test result table.

The patient table consists of 10 fields:

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PATIENTID</td>
<td>identification number;</td>
</tr>
<tr>
<td>FIRSTNAME</td>
<td>name of the patient;</td>
</tr>
<tr>
<td>LASTNAME</td>
<td>surname of the patient;</td>
</tr>
<tr>
<td>DATEOFBIRTH</td>
<td>date of birth;</td>
</tr>
<tr>
<td>SEX</td>
<td>gender;</td>
</tr>
<tr>
<td>ADDRESS</td>
<td>address of the patient;</td>
</tr>
<tr>
<td>PHONE</td>
<td>telephone number;</td>
</tr>
<tr>
<td>EMAIL</td>
<td>e-mail of the patient;</td>
</tr>
<tr>
<td>FAMILYDOCTOR</td>
<td>patient's family doctor;</td>
</tr>
<tr>
<td>IDNUMBER</td>
<td>personal code of the patient</td>
</tr>
</tbody>
</table>

This software can be improved with a data sending module, so it is recommended to fill in as many fields as possible. The patient table can be seen in Fig. 5.
The test result table consists of 6 fields (Fig. 6). All of them are filled automatically during the testing process. The table consists of:

- **MERIJUMIID**: identification number of the test;
- **PATIENDID**: identifications number of the patient;
- **DATETIME**: date and time of the test;
- **IDIKACIJAS**: all indications that are selected;
- **KONTRINDIKACIJAS**: all contraindications that are selected as “YES”;
- **TERAPIJA**: decision on therapy.

After returning to the main window (Fig. 7) and pressing on the button “Tests”, a new form will open where the selected patient’s history of test results will be shown. As it can be seen in Fig. 9 the patient “Testa Pacients” has got no tests completed yet and all fields are empty. The software has been developed so that the doctor can come back and check the test results any time. If there is at least one test completed for the selected patient, under the label “Veiktie testi”, all tests will be sorted by date and time, and by pressing on one of them the test results will appear under the label “Testa rezultāti”. It is really useful because the doctor can compare older results with the new ones. The button “Jauns tests…” will start a new test, but “Aizvērt” will close this form and return to the main window (Fig. 9).

To start a new test the doctor must press on the button “Jauns tests…”. A new form will open where the doctor must check all patient’s identified features that have been diagnosed. When it is done the doctor can press on the button “Tālāk” to go further or “Atcelt” to cancel all and to close the test form (Fig. 10).

When the doctor presses on “Tālāk”, the software will make a decision whether it is a treatment with medication or surgical therapies are needed. In case the patient must be treated by the surgical method, a new form will open where the doctor must check all diagnosed indications (Fig. 11). To go further the doctor must press on the button “Tālāk” or “Atcelt” to discard changes and close this form.
When all diagnosed indications are checked, the doctor must press on the button “Tālāk”. A new form will open, where the doctor must answer all questions from top to bottom. By default all answers are set to “NO”, because it is the best possible situation when the patient has got no contraindications at all (Fig. 12). When the doctor has answered all questions, the program is ready to make the decision about the treatment which can be obtained by pressing on the button “Sliedziens”.

The Decision about the therapy is given in a new form. All selected indications and contraindications are shown too. The doctor can compare his opinion to the one given by the software. The decision form can be seen in Fig. 13.

If the doctor presses button “OK” in the decision form, the test results will be saved in the database and the active form will be closed. If the doctor presses on “Atcelt”, the test results will not be saved and the active window will be closed. Now it is possible to check the history of the selected patient’s test results because they are saved in the database. The selected patient’s test results can be seen in Fig. 14.

V. RESULT AND CONCLUSION

The proposed system allows to perform a quick and efficient testing. It is very flexible and supports different hardware. The software was tested by using real life cases. The attending physician completed this test in real life situations and compared the given decision of therapy with his own decision. The given software was accepted as fully working. There are no fundamental mistakes in the production rule logics because they were confirmed by certified urologist and were signed and stamped.

To create a computerized decision-making by using decision trees and production rules, one of the main tasks was to create synthesis of these two elements. One of the most important stages was knowledge formalization and structuring. Extensive knowledge of the disease development and the patient is needed to choose the optimal therapy. A fully working computer program has been developed and the attending physician can use and test it in practice.

REFERENCES

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